

Measurement of the UT angle ϕ_2

GAGAN B. MOHANTY

*Tata Institute of Fundamental Research
Homi Bhabha Road, Mumbai 400 005, INDIA***Abstract**

We give a status report on measurements of the angle $\phi_2(\alpha)$ of the CKM unitarity triangle (UT) and the so-called $K\pi$ puzzle. Results presented are mostly from the two B -factory experiments, Belle and BaBar.

PRESENTED AT

The Ninth International Conference on
Flavor Physics and CP Violation
(FPCP 2011)
Maale Hachamisha, Israel, May 23–27, 2011

1 Introduction

B meson decays provide an excellent laboratory to test CP violation mechanism in the standard model (SM), which is attributed to an irreducible phase appearing in the quark-flavor mixing matrix, known as the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1]. Unitarity of the 3×3 CKM matrix can be conveniently depicted as a set of triangles in the complex plane, one of which is the so-called unitarity triangle (UT) that connects matrix elements of the first and third row. One of the major goals for heavy flavor experiments of the last few decades – be it the two B -factory experiments of Belle [2] and BaBar [3], or the recently-started LHCb experiment [4] – has been to precisely measure the sides and angles $(\phi_1, \phi_2 \text{ and } \phi_3)^*$ of the UT. In doing so, experimenters aim to verify whether the CKM framework is the correct description of CP violation in the SM, and to constrain possible new physics effects that could lead to internal inconsistencies among various measurements. In these proceedings, we present a minireview on the measurement of the angle ϕ_2 carried out at Belle and BaBar, followed by a brief report on the $K\pi$ puzzle.

2 Enter the angle ϕ_2

The UT angle $\phi_2 = \arg(-V_{td}V_{tb}^*/V_{ud}V_{ub}^*)$ brings to fore two CKM matrix elements that are complex at the lowest order: V_{ub} , involved in decays proceeding via a $b \rightarrow u$ tree-level transition with phase $-\phi_3$, and V_{td} , involved in $B^0\bar{B}^0$ mixing having phase equals to $-\phi_1$. Therefore, $\phi_2 = \pi - \phi_1 - \phi_3$ can be extracted from time-dependent CP violation asymmetries in the interference between decay and mixing in $b \rightarrow u$ tree-dominated decays of neutral B mesons, such as $B^0 \rightarrow \pi^+\pi^-$, $\rho^+\rho^-$ and $\pi^+\pi^-\pi^0$.

At the B factories, the measured time-dependent CP asymmetry can be given by

$$A_{CP}(f; t) \equiv \frac{N[\bar{B}^0(t) \rightarrow f] - N[B^0(t) \rightarrow f]}{N[\bar{B}^0(t) \rightarrow f] + N[B^0(t) \rightarrow f]} = S_f \sin(\Delta m t) + A_f \cos(\Delta m t), \quad (1)$$

where $N[\bar{B}^0/B^0(t) \rightarrow f]$ is the number of \bar{B}^0/B^0 s that decay to a common CP eigenstate f after time t and Δm is the mass difference between the two neutral B mass eigenstates. The coefficients $S_f = \frac{2\text{Im}(\lambda_f)}{|\lambda_f|^2+1}$ and $A_f = \frac{|\lambda_f|^2-1}{|\lambda_f|^2+1}$ are functions of the ratio of the decay amplitudes with and without mixing, $\lambda_f = \frac{q}{p}\bar{\mathcal{A}}_f/\mathcal{A}_f$. Here the ratio $\frac{q}{p}$ accounts for $B^0\bar{B}^0$ mixing; S_f and A_f are the measure of mixing-induced and direct CP violation, respectively. Note that BaBar uses a notation $C_f = -A_f$.

In the scenario where the neutral B meson decays involve only $b \rightarrow u$ transition, λ_f is $e^{-i2(\phi_1+\phi_3)} = e^{i2\phi_2}$ resulting in $S_f = \sin(2\phi_2)$ and $A_f = 0$. This is expected as direct CP violation, i.e., nonzero A_f arises when there are at least two competing

*An equally popular notation of α , β and γ is also available in the literature.

decay amplitudes of different weak phase. Had that been the case, a time-dependent CP analysis in the mode would have provided a clean access to ϕ_2 . The real situation, however, is murkier due to the presence of possible $b \rightarrow d$ penguin (loop) diagram, which does not carry the same weak phase as the tree amplitude. As a result, the measured A_f is no longer equal to zero and the mixing-induced term becomes $S_f = \sqrt{1 - A_f^2} \sin(2\phi_2^{\text{eff}})$, where ϕ_2^{eff} is an effective ϕ_2 that differs from the true value because of the penguin pollution.

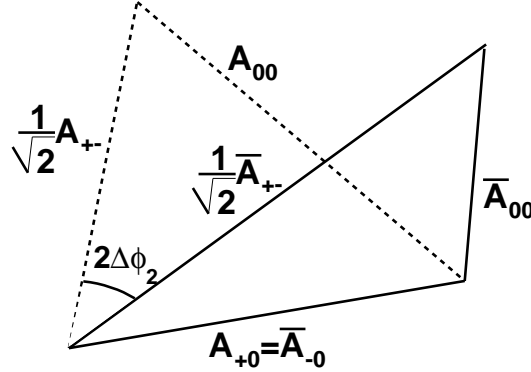


Figure 1: Graphical representation of the isospin relations.

Gronau and London have proposed a model-independent method [5] based on $SU(2)$ isospin for extracting the difference $\Delta\phi_2 = \phi_2 - \phi_2^{\text{eff}}$, which would allow one to recover the true value of ϕ_2 . Let us denote the $B^{ij} \rightarrow h^i h^j$ and $\bar{B}^{ij} \rightarrow h^i h^j$ ($h = \pi$ or ρ and $i, j = +, -, 0$) decay amplitudes \mathcal{A}_{ij} and $\bar{\mathcal{A}}_{ij}$, respectively. Assuming $SU(2)$ isospin symmetry, these amplitudes are related by

$$\frac{1}{\sqrt{2}}\mathcal{A}_{+-} + \mathcal{A}_{00} = \mathcal{A}_{+0}, \quad \frac{1}{\sqrt{2}}\bar{\mathcal{A}}_{+-} + \bar{\mathcal{A}}_{00} = \bar{\mathcal{A}}_{-0}, \quad (2)$$

which can be represented graphically as triangles in the complex plane (see Fig. 1). Neglecting electroweak penguins, $|\mathcal{A}_{+0}| = |\bar{\mathcal{A}}_{-0}|$ (evidence for large CP asymmetry in $B^\pm \rightarrow h^\pm h^0$, if found, would show that such contributions cannot be neglected and hence would invalidate the equality). If the global phase of all \mathcal{A}_{ij} is chosen such that $\mathcal{A}_{+0} = \bar{\mathcal{A}}_{-0}$, then the phase difference between \mathcal{A}_{+-} and $\bar{\mathcal{A}}_{+-}$ would be $2\Delta\phi_2$, as shown in Fig. 1. Since both \mathcal{A} and $\bar{\mathcal{A}}$ triangles have two possible orientations, up and down, the isospin method carries a four-fold ambiguity, which comes on top of the two-fold ambiguity arising from the fact that only the sine of ϕ_2^{eff} is measured in time-dependent analyses of $B^0 \rightarrow h^+ h^-$.

3 ϕ_2 from $B \rightarrow \pi\pi$

In order to determine ϕ_2 in $B \rightarrow \pi\pi$ decays using the isospin method, one needs six observables: mixing-induced as well as direct CP asymmetries in $B^0 \rightarrow \pi^+\pi^-$, branching fractions for $B^0 \rightarrow \pi^+\pi^-$, $B^+ \rightarrow \pi^+\pi^0$, and $B^0 \rightarrow \pi^0\pi^0$ and the direct CP asymmetry in $B^0 \rightarrow \pi^0\pi^0$. Table 1 summarizes results on these observables as measured by Belle [6] and BaBar [7]. Except for $A_{\pi^0\pi^0}$ both experiments exhibit similar sensitivities. In this table, we also present CP asymmetry results for the channel $B^+ \rightarrow \pi^+\pi^0$, which are found to be consistent with zero, corroborating our earlier assumption of negligible electroweak penguin contribution.

In Fig. 2 we plot results of the time-dependent CP fit performed by Belle and BaBar in the decays $B^0 \rightarrow \pi^+\pi^-$. Both experiments observe nonzero mixing-induced CP asymmetry. As far as the direct CP violation part is concerned Belle observe it with a significance of 5.5 standard deviations (σ), whereas BaBar find a 3.0σ evidence. Using the isospin analysis, Belle determine four different solutions consistent with their data. The solution consistent with the SM inferred value, $(100^{+5}_{-7})^\circ$ [8], yields $\phi_2 = (97 \pm 11)^\circ$. Belle also exclude the interval $11^\circ < \phi_2 < 79^\circ$ at the 95% confidence level (CL). BaBar on the other hand set an 1σ range for ϕ_2 between 71° and 109° , excluding $\phi_2 \in [23^\circ, 67^\circ]$ at the 90% CL. As evident from Table 1 the current precision on the measurements of $B^0 \rightarrow \pi^0\pi^0$, related to \mathcal{A}_{00} and $\bar{\mathcal{A}}_{00}$ of the isospin relations in Eq. (2), is the limiting factor in the extraction of ϕ_2 in $B \rightarrow \pi\pi$.

Table 1: Summary of physics observables measured in $B \rightarrow \pi\pi$ decays. First uncertainties are statistical and second are systematic. Values in square brackets denote numbers of $B\bar{B}$ events (M stands for million) in the data sample used in the analysis.

	Belle		BaBar	
$S_{\pi^+\pi^-}$	$-0.61 \pm 0.10 \pm 0.04$	[535 M]	$-0.68 \pm 0.10 \pm 0.03$	[467 M]
$A_{\pi^+\pi^-}$	$+0.55 \pm 0.08 \pm 0.05$	[535 M]	$+0.25 \pm 0.08 \pm 0.02$	[467 M]
$\mathcal{B}(B^0 \rightarrow \pi^+\pi^-)$	$(5.1 \pm 0.2 \pm 0.2) \times 10^{-6}$	[449 M]	$(5.5 \pm 0.4 \pm 0.3) \times 10^{-6}$	[227 M]
$\mathcal{B}(B^+ \rightarrow \pi^+\pi^0)$	$(6.5 \pm 0.4 \pm 0.4) \times 10^{-6}$	[449 M]	$(5.02 \pm 0.46 \pm 0.29) \times 10^{-6}$	[383 M]
$A_{\pi^+\pi^0}$	$+0.07 \pm 0.06 \pm 0.01$	[535 M]	$+0.03 \pm 0.08 \pm 0.01$	[383 M]
$\mathcal{B}(B^0 \rightarrow \pi^0\pi^0)$	$(1.1 \pm 0.3 \pm 0.1) \times 10^{-6}$	[535 M]	$(1.83 \pm 0.21 \pm 0.13) \times 10^{-6}$	[467 M]
$A_{\pi^0\pi^0}$	$+0.44^{+0.73+0.04}_{-0.62-0.06}$	[535 M]	$+0.43 \pm 0.26 \pm 0.05$	[467 M]

4 ϕ_2 from $B \rightarrow (\rho\pi)^0$

The decays $B^0 \rightarrow \rho^+\pi^-$, $B^0 \rightarrow \rho^-\pi^+$, and $B^0 \rightarrow \rho^0\pi^0$ [collectively referred to as $B \rightarrow (\rho\pi)^0$] are not a CP eigenstate unlike $B \rightarrow \pi\pi$ or $B \rightarrow \rho\rho$. As a result, the time-dependent parameters S_f and A_f measured in these decays are no more

purely CP violating in nature; they contain a CP conserving part too. The problem gets further complicated as the decays involve four isospin amplitudes leading to 12 unknowns in the isospin pentagon. Synder and Quinn have suggested a theoretically cute idea [9] to determine ϕ_2 without any discrete, trigonometric ambiguity using a time-dependent Dalitz plot (TDPA) analysis of $\pi^+\pi^-\pi^0$, which is the end product of the $B \rightarrow (\rho\pi)^0$ decays. The basic philosophy behind their idea is to exploit the strong phase variation of the interfering ρ resonances over the three-pion Dalitz plot.

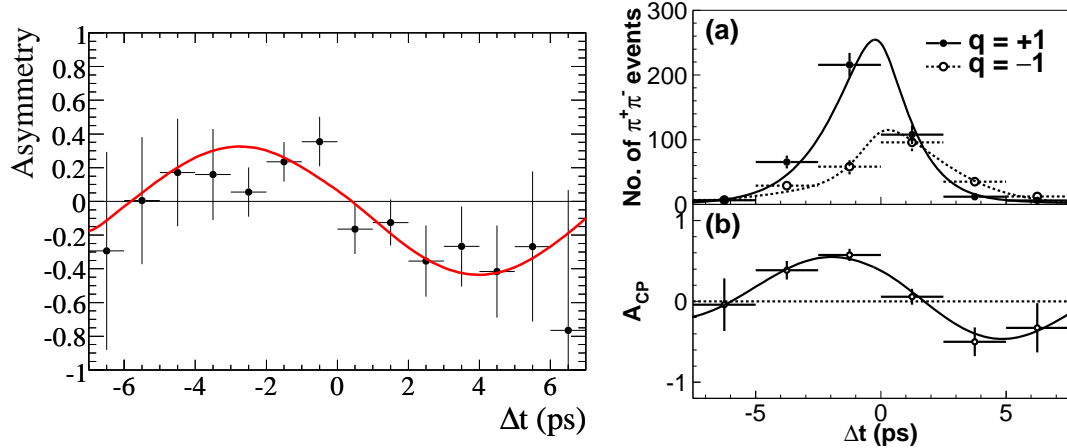


Figure 2: The left plot shows the time-dependent asymmetry measured by BaBar in $B^0 \rightarrow \pi^+\pi^-$. The right plots from Belle are (a) results of the fit to proper time distributions for the aforementioned decays tagged as either $B^0(q = +1)$ or $\bar{B}^0(q = -1)$, and (b) the resultant asymmetry. Mixing-induced CP violation can be clearly seen from the asymmetry plots, and the height difference between B^0 - and \bar{B}^0 -tagged decays (see the top right plot) is a signature of direct CP violation.

Both Belle [10] and BaBar [11] have performed the TDPA analysis using a dataset of 449 M and 375 M $B\bar{B}$ events, respectively. These analyses are essentially based on a fit to 27 bilinear coefficients [12]. All the 27 observables are not independent. There are in fact 12 free parameters in the fit corresponding to the six amplitudes \mathcal{A}_i and $\bar{\mathcal{A}}_i$ ($i = +, -, \text{ and } 0$ represent $\rho^+\pi^-, \rho^-\pi^+, \text{ and } \rho^0\pi^0$, respectively). After factoring out the overall normalization and phase factor along with two isospin relations for the neutral B decays, one is left with eight free parameters. To constrain ϕ_2 , a χ^2 is built out of the 26 bilinear coefficients (one of them is fixed as the overall normalization) after taking correlations between them into account. A scan is performed over all possible values of ϕ_2 , where each of the eight independent parameters are varied in order to minimize the χ^2 . The resulting change in the χ^2 from its minimum is translated into a CL. In Fig. 3 we present results of 1-CL versus ϕ_2 obtained by the two experiments. BaBar quote $\phi_2 = (87^{+45}_{-13})^\circ$; almost no constraint is achieved at the 2σ interval. In conjunction with additional constraints from the charged modes

$B^+ \rightarrow \rho^0 \pi^+$ and $B^+ \rightarrow \rho^+ \pi^0$ [13], Belle derive the constraint $68^\circ < \phi_2 < 95^\circ$ at 68.3% CL for the solution consistent with the SM [8].

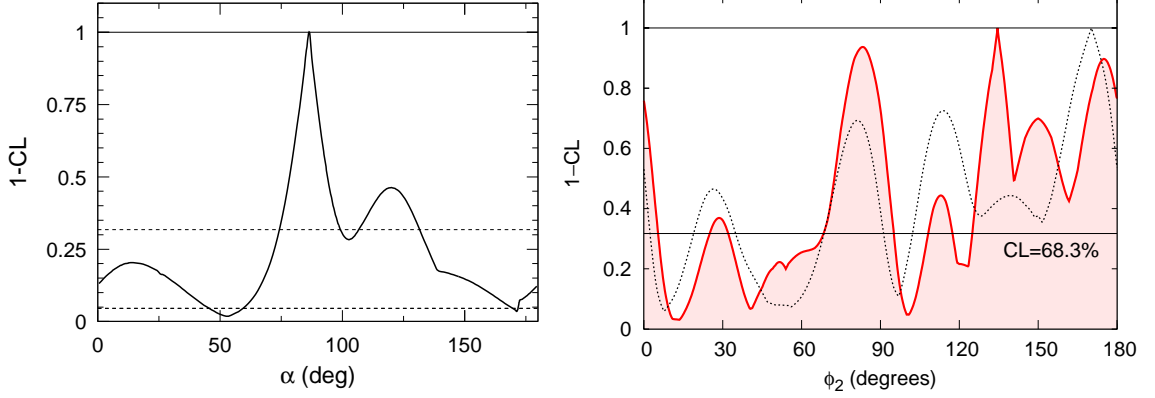


Figure 3: $1-\text{CL}$ versus ϕ_2 from BaBar (left) and Belle (right) obtained in the analysis of $B \rightarrow (\rho\pi)^0 \rightarrow \pi^+\pi^-\pi^0$. In the left plot the dashed horizontal lines near $1-\text{CL} = 0.317$ and 0.050 represent the 1σ and 2σ confidence intervals, respectively. For Belle, the dashed curve corresponds to the nine-parameter fit (including ϕ_2) while the solid (red) curve includes additional constraints from $B^+ \rightarrow \rho^0 \pi^+$ and $B^+ \rightarrow \rho^+ \pi^0$.

5 ϕ_2 from $B \rightarrow \rho\rho$

The decays $B \rightarrow \rho\rho$ comes with a complication that two fairly wide, spin-1 mesons are present in the final state having a relative orbital angular momentum, $L = 0, 1, 2$. As the CP eigenvalue for $B^0 \rightarrow \rho^+\rho^-$ is $(-1)^L$, it becomes necessary to separate out the two distinct CP components (CP -even for $L = 0, 2$ and -odd for $L = 1$) through an angular analysis for constraining ϕ_2 . In other word, the extraction of ϕ_2 requires knowledge of polarization. At the B factories, one simultaneously measures the branching fraction as well as the fraction of longitudinal polarization (f_L) by fitting the angular decay rate

$$\frac{d^2 N}{d \cos \theta_1 d \cos \theta_2} = 4f_L \cos^2 \theta_1 \cos^2 \theta_2 + (1 - f_L) \sin^2 \theta_1 \sin^2 \theta_2, \quad (3)$$

where $\theta_1(\theta_2)$ is the helicity angle of the $\rho^+(\rho^-)$ meson. The two terms in the right hand side correspond to the contribution of the longitudinal and transverse component, respectively. Table 2 summarizes results from Belle [14] and BaBar [15] on the branching fraction, f_L , and time-dependent CP violation parameters $S_{\rho^+\rho^-}$ and $A_{\rho^+\rho^-}$. The f_L value being very much closer to unity tells us that $B^0 \rightarrow \rho^+\rho^-$ is dominated by the CP -even, longitudinal amplitude (the same conclusion also holds

for $B^+ \rightarrow \rho^+ \rho^0$ and $B^0 \rightarrow \rho^0 \rho^0$). Therefore, the transverse component can be safely ignored in the extraction ϕ_2 . The measured values $S_{\rho^+ \rho^-}$ and $A_{\rho^+ \rho^-}$ are found to be consistent with zero, ruling out a large contribution from the $b \rightarrow d$ penguin amplitude.

Table 2: Summary of physics observables measured in $B \rightarrow \rho\rho$ decays. First uncertainties are statistical and second are systematic. Values in square brackets denote numbers of $B\bar{B}$ events in the data sample used in the analysis.

	Belle		BaBar	
$\mathcal{B}(B^0 \rightarrow \rho^+ \rho^-)$	$(22.8 \pm 3.8^{+2.3}_{-2.6}) \times 10^{-6}$	[275 M]	$(25.5 \pm 2.1^{+3.6}_{-3.9}) \times 10^{-6}$	[384 M]
$f_L(B^0 \rightarrow \rho^+ \rho^-)$	$0.941^{+0.034}_{-0.040} \pm 0.030$	[275 M]	$0.992 \pm 0.024^{+0.026}_{-0.013}$	[384 M]
$S_{\rho^+ \rho^-}$	$+0.19 \pm 0.30 \pm 0.08$	[535 M]	$-0.17 \pm 0.20^{+0.05}_{-0.06}$	[384 M]
$A_{\rho^+ \rho^-}$	$+0.16 \pm 0.21 \pm 0.08$	[535 M]	$-0.01 \pm 0.15 \pm 0.06$	[384 M]
$\mathcal{B}(B^+ \rightarrow \rho^+ \rho^0)$	$(31.7 \pm 7.1^{+3.8}_{-6.7}) \times 10^{-6}$	[85 M]	$(23.7 \pm 1.4 \pm 1.4) \times 10^{-6}$	[465 M]
$f_L(B^+ \rightarrow \rho^+ \rho^0)$	$0.95 \pm 0.11 \pm 0.02$	[85 M]	$0.950 \pm 0.015 \pm 0.006$	[465 M]
$A_{\rho^+ \rho^0}$	$+0.00 \pm 0.22 \pm 0.03$	[85 M]	$-0.054 \pm 0.055 \pm 0.010$	[465 M]
$\mathcal{B}(B^0 \rightarrow \rho^0 \rho^0)$	$< 1.0 \times 10^{-6}$ at 90% CL	[657 M]	$(0.92 \pm 0.32 \pm 0.14) \times 10^{-6}$	[465 M]
$f_L(B^0 \rightarrow \rho^0 \rho^0)$	—	—	$0.75^{+0.11}_{-0.14} \pm 0.04$	[465 M]
$S_{\rho^0 \rho^0}$	—	—	$+0.3 \pm 0.7 \pm 0.2$	[465 M]
$A_{\rho^0 \rho^0}$	—	—	$-0.2 \pm 0.8 \pm 0.3$	[465 M]

Results from Belle and BaBar on $B^+ \rightarrow \rho^+ \rho^0$ and $B^0 \rightarrow \rho^0 \rho^0$ are also presented in Table 2. In case of $B^+ \rightarrow \rho^+ \rho^0$ BaBar obtain a pretty large branching fraction, which leads to a strong constraint on the isospin triangles and subsequently to a precise determination of ϕ_2 (see the discussion below), and a CP asymmetry consistent with zero, showing no evidence for isospin violation. Belle’s earlier results based on a much smaller dataset than available today agree with these measurements – obviously with larger errors. For $B^0 \rightarrow \rho^0 \rho^0$, although it is presumed to be easy to identify having four charged pions in the final state, one suffers due to relatively low branching fraction in the face of multiple backgrounds with the identical final state. BaBar report a first evidence for the decay with a 3.1σ significance in addition to performing a time-dependent study. Belle on the other hand quote a 90% CL upper limit on the branching fraction. In Fig. 4 we show the constraints on ϕ_2 resulting from $B \rightarrow \rho\rho$ in. The results are $\phi_2 = (91.7 \pm 14.9)^\circ$ and $(92.4^{+6.0}_{-6.5})^\circ$ from Belle and BaBar, respectively.

6 Closing Words on ϕ_2

The current world-average of ϕ_2 [8] including all relevant measurements of $B \rightarrow \pi\pi$, $B \rightarrow \rho\pi$ and $B \rightarrow \rho\rho$ from Belle and BaBar reads $(89.0^{+4.4}_{-4.2})^\circ$ – almost a precision measurement. Another averaging method [16] based on a different statistical

treatment also yields a compatible result. The world-average value is mostly decided by the results of $B \rightarrow \rho\rho$. In particular, the large branching fraction for $B^+ \rightarrow \rho^+\rho^0$ relative to $B^0 \rightarrow \rho^0\rho^0$ reported by BaBar is responsible in collapsing two previously degenerated mirror solutions of the isospin relations, inherent to the method, into a single one. The two isospin triangles in fact do not close any more [8]. This may sound a bit of jocular; to start with we assume the SU(2) constraint for extracting ϕ_2 , while the end result is a violation of the triangular relation, but yields a precision measurement! We are truly in a lucky situation, and therefore it is very important to have the updated results from Belle with their full $\Upsilon(4S)$ data sample. Furthermore, more precise results on $B^0 \rightarrow \pi^0\pi^0$, which can only be carried out at the pristine e^+e^- environment of the B factories, would play a good supporting role. Last but not least, one should not forget about the mode $B \rightarrow (\rho\pi)^0$, which provides a clean measure of ϕ_2 without any trigonometric ambiguity. It would be imperative to carry out these important measurements with much more data at the next-generation flavor factories, SuperKEKB in Japan [17] and SuperB in Italy [18].

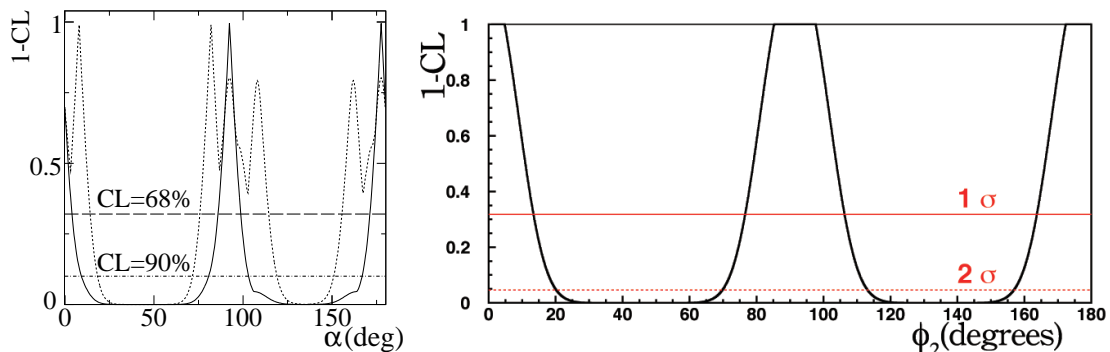


Figure 4: 1-CL versus ϕ_2 from BaBar (left) and Belle (right) obtained with the analysis of $B \rightarrow \rho\rho$. BaBar's constraint is based solely on their results. The dashed curve indicates situation prior to the updated result of $B^+ \rightarrow \rho^+\rho^0$ while the solid curve includes that. Belle use their own results on $B^0 \rightarrow \rho^0\rho^0$ plus world-averages for the rest. The latter exercise was carried out before BaBar's update on $B^+ \rightarrow \rho^+\rho^0$, and a plateau is present as there is no constraint on $A_{\rho^0\rho^0}$.

7 The $K\pi$ Puzzle

As alluded earlier, direct CP violation arises when we have contributions from two competing amplitudes of different weak phases. For the decays $B^0 \rightarrow K^+\pi^-$ and $B^+ \rightarrow K^+\pi^0$, that are assumed to proceed via similar Feynman's diagrams at the tree level, one expects to see the magnitude of CP violation to be same. In contrast, the measured CP asymmetry in $B^0 \rightarrow K^+\pi^-$ is $(-9.8^{+1.2}_{-1.1})\%$, whereas the same for

$B^+ \rightarrow K^+\pi^0$ reads $(+5.0 \pm 2.5)\%$. This apparent large gap [13] between the two measurements [$\Delta A_{K\pi} = (-14.4 \pm 2.9)\%$] is better known as the $K\pi$ puzzle. The jury is out whether this could be due to a large contribution from the color-suppressed tree diagram, or an enhanced electroweak penguin amplitude, or Pauli blocking, as it has been recently claimed [19]. But still, it is fair to say that possible smoking gun for new physics [20] is not unequivocally ruled out. On this account, it would be good to improve the precision on CP violation results for $B^0 \rightarrow K^0\pi^0$ in order to test the sum rule [21]. Data from the super flavor factories [17, 18] are expected to play a decisive role on resolving this $K\pi$ conundrum.

ACKNOWLEDGEMENTS

We thank Karim Trabelsi for reading the proceedings and making useful suggestions. This work is supported in parts by the Department of Atomic Energy and the Department of Science and Technology of India.

References

- [1] N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).
- [2] A. Abashian *et al.* (Belle Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 117 (2002).
- [3] B. Aubert *et al.* (BaBar Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).
- [4] A. Augusto Alves *et al.* (LHCb Collaboration), JINST **3**, S08005 (2008).
- [5] M. Gronau and D. London, Phys. Rev. Lett. **65**, 3381 (1990).
- [6] H. Ishino *et al.* (Belle Collaboration), Phys. Rev. Lett. **98**, 211801 (2007); S.-W. Lin *et al.* (Belle Collaboration), Phys. Rev. Lett. **99**, 121601 (2007); S.-W. Lin *et al.* (Belle Collaboration), Nature **452**, 332 (2008); K. Abe *et al.* (Belle Collaboration), arXiv:hep-ex/0610065.
- [7] B. Aubert *et al.* (BaBar Collaboration), arXiv:0807.4226[hep-ex]; B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **75**, 012008 (2007); B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **76**, 091102 (2007).
- [8] J. Charles *et al.* (CKMfitter Group), Eur. Phys. J. C **41**, 1 (2005); For online updates see <http://ckmfitter.in2p3.fr/>.

- [9] A.E. Synder and H.R. Quinn, Phys. Rev. D **48**, 2139 (1993).
- [10] A. Kusaka *et al.* (Belle Collaboration), Phys. Rev. Lett. **98**, 221602 (2007); A. Kusaka *et al.* (Belle Collaboration), Phys. Rev. D **77**, 072001 (2008).
- [11] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **76**, 012004 (2007).
- [12] H.R. Quinn and J.P. Silva, Phys. Rev. D **62**, 054002 (2000).
- [13] E. Barberio *et al.* (Heavy Flavor Averaging Group), arXiv:hep-ex/0603003; For online updates see <http://www.slac.stanford.edu/xorg/hfag/>.
- [14] A. Somov *et al.* (Belle Collaboration), Phys. Rev. D **76**, 011104 (2007); A. Somov *et al.* (Belle Collaboration), Phys. Rev. Lett. **96**, 171801 (2006); J. Zhang *et al.* (Belle Collaboration), Phys. Rev. Lett. **91**, 221801 (2003).
- [15] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **76**, 052007 (2007); B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. Lett. **97**, 261801 (2006); B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **78**, 071104 (2008).
- [16] M. Bona *et al.* (UTfit Collaboration), JHEP **0507**, 028 (2005); For online updates see <http://www.utfit.org/>.
- [17] T. Abe *et al.* (Belle II Collaboration), arXiv:1011.0352[hep-ex].
- [18] M. Bona *et al.* (SuperB Collaboration), arXiv:0709.0451[hep-ex].
- [19] H.J. Lipkin, contribution to these proceedings and arXiv:1105.3443[hep-ph].
- [20] W.-S. Hou, M. Nagashima, and A. Soddu, Phys. Rev. Lett. **95**, 141601 (2005); R. Fleischer, S. Recksiegel, and F. Schwab, Eur. Phys. J. C **51**, 55 (2007); L. Hofer, D. Scherer, and L. Vernazza, JHEP **1102**, 080 (2011).
- [21] M. Gronau, Phys. Lett. B **627**, 82 (2005).